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Schau, Holger; Beier, Hendrik:

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Practice-oriented test standard for the evaluation of protective clothing against the risks of an electrical arc – CLC/TS 50354 Box Test

Holger Schau[1], Hendrik Beier[2]
[1]Technische Universität Ilmenau, Germany
[2]Sächsisches Textilforschungsinstitut e.V., Germany

Abstract
Electric arcs are a potential risk for people and plant. Particularly the protection against electric fault arcs is of largest importance for human injury while working in, at or near to electric power installations. An essential contribution to this protection can be made by clothing. Protective clothing must be tested under real-life and reproducible conditions.

1. Test requirements

There is a general hazard and potential risk of human injury due to electric arcs particularly in case of fault arcs which may internally occur with short-circuits in electric installations. These arcs cannot be avoided totally. In particular those people are concerned by this, working at, in or near to these installations for professional reasons. Their working clothing may essentially contribute to protect them particularly against the thermal arc consequences or be actually a base for the according protection.

It is of greatest importance for the personnel mounting, repairing, maintaining or operating electrical equipment and installations to be safely protected in each situation actually. There may not result any unacceptable health risk, the suitability of clothing has to be analysed and proved. A reliable test is necessary to confirm the working clothing to be arc resistant and guaranteeing the protective level required. Test method, procedure, set-up and parameters must meet the according practical needs. The test conditions have to be selected and terminated in accordance with the relevant power network and installation ones, and the practical exposure scenarios as well. Furthermore, quantitative assessment and evaluation is necessary in testing. The calorimetric arc effects are to be measured, a calorimetric analysis of the tests has to be carried out.

2. Arc test methods

In the international standard IEC 61482 Part 1 there will be two principle test methods in next future. Both methods have already being used in practice for several years. They show differences in the test targets and procedures as well.

The new IEC 61482-1-1 presently being under maintenance, specifies methods directed to determine a material property parameter: the ATPV – arc thermal performance value [1]. This ATPV is used to assess the material or garment of a clothing with respect to its protection effect against thermal arc consequences. In US and Canada working activities have been classified by means of ATPV levels for a few years. There are standards and recommendations for categorisation. From risk assessment is known what ATPV has to be required or observed for a certain work. The IEC 61482-1-1 test is based on an open arc fired in a 6 or 10 kV test circuit (MV conditions) between electrodes with a 30 cm spacing. It is oriented to the specifics and requirements in Northern America and also used mainly there.

In Europe there are only few experiences regarding this ATPV classification and application. Therefore, another test method has been established and set up here. It is widely spread in testing and certificating material and clothing. This method will be specified in the new IEC 61482-1-2 which is under consideration presently [2].

This part of IEC 61482 specifies procedures to test materials and garments intended for use in heat- and flame-resistant clothing for workers exposed to electric arcs. In difference to test methods in IEC 61482-1-1 a directed and constrained electric arc in a low voltage circuit will be used. The test method is aimed to give a decision if arc thermal protection is met under defined conditions. Two protection classes can optionally be tested. Protection class 1 and 2 are safety requirements covering actual risk potentials due to electric fault arcs to a very large extent. The test methods are not directed to measure the ATPV.

In this so-called Box Test materials, material-assemblies and protective clothing is evaluated using a directed and constrained electric arc under defined laboratory conditions. A practical scenario concerning test set-up and test conditions, electrical and constructional parameters is selected. The test conditions represent the typical low voltage environmental ones during service. As shown by statistics, serious electrical accident with fault arcs occur in LV power installations mainly.

Test set up and conditions are based on the specifications of CENELEC TS 50354 (former existing as pre-standard ENV 50354) [3]. In the Box Test the procedure is extended and supplemented by a quantitative measurement of the heat flux or energy transmitted through the material. The procedure was developed and improved at the Technische Universität Ilmenau in co-operation with the Saxon Textile Research Institute Chemnitz (STFI) in Germany. In the following this Box Test will be considered in more detail.

3. Box Test method

3.1. Principle of testing

The box test is tailored to the special European needs. The arc resistance is assessed for two different protection classes. Difference is made with respect to the test current level, being also criterion for the practical use in reference to the short-circuit currents in the electric system. An electric arc is fired in a 400 V AC test circuit, burning between two vertically arranged electrodes which are surrounded by a special test box. Test circuit parameters and set-up ones (current, duration, distances,...) remain unchanged within a test series which is necessary for statistical reasons. In testing it is assessed if the requirements of the protection class are observed. Limits for practical use of tested materials are given with these test conditions. Conditions simulated by the tests are worst case ones for switchgear assemblies and installations in LV power systems in the according short-circuit current range. They also allow to take into account, additionally to those of radiation and convection, the thermal arc consequences which may result from the amplifying effect of installation back and side walls, too. Furthermore, these of metal splashes and vapour accompanying all real fault arc processes, are considered.

The test parameters of both protection classes are summarized in **Tab. 1**.

Table 1. Test parameters and conditions

			tolerance
test current	class 1 4 kA	class 2 7 kA	+/- 5 %
test voltage	400 V AC, 50 Hz		+/- 5 %
arcing time	0.5 s		+/- 5 %
electrodes	aluminium (top) copper (bottom)		
electrode gap	30 mm		+/- 1 mm
distance a	300 mm		+/- 5 mm

a – distance arc to calorimeter respectively to test specimen

Bright experiences in testing by using this method confirm the tests to be very close to practice as well as reproducible. In addition to a visual assessment regarding after flame, hole formation, shrinking etc.) a quantitative criterion is provided as the test result, with measuring the temperature rise or the incident energy behind the test samples. Special calorimeters are used, allowing an evaluation by comparing with limiting values of the onset of second degree burns of human skin [4]. Conclusions may be drawn whether the heat flux conditions resulting from using the tested material are acceptable from the personal protection point of view. Comparing measured incident energy values of both with and without test sample, the material effect may be quantified.

3.2. Arc testing with calorimetric analysis

The principle of the test is shown in **Fig. 1**. A free-burning high-current arc of defined input power P_{LB} and duration t_p is reproducibly fired in an electric test circuit (test voltage U_p, test current I_p). The arc is ignited by means of a fuse wire by switching-on the voltage and, after the burning interval t_p of 500 ms, switched-off by circuit breaker. The arc energy W_{el} is converted during the arc duration.

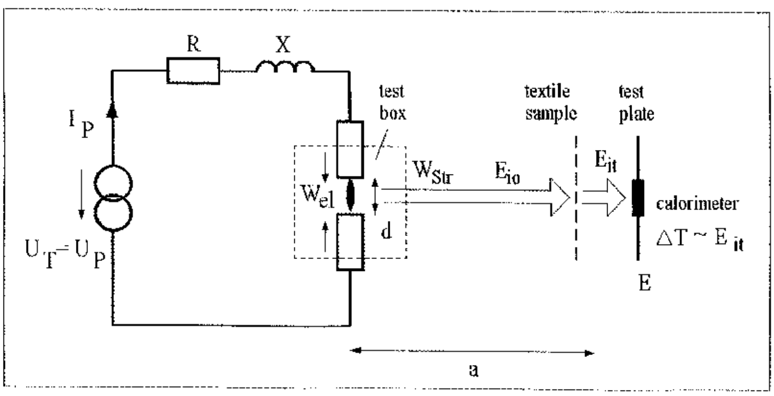

Fig. 1. Principle of testing

The arc burning volume is limited by a test box surrounding the arc. Radial, the box is open to only one side, a directing effect of arc heat radiation and flux results (without box a diffuse spread to all direction would appear). A test plate or mannequin is placed in this direction, carrying the test samples and where the calorimeters are located for measuring the temperature rise dT or incident energy E_i and heat flux Q, respectively. In case of direct arc expose (without test sample) the calorimeters measure the maximum heat (total heat) E_{io}. When being covered by the test sample, the calorimeters indicate the incident energy transmitted E_{it}.

The characterizing electric and calorimetric parameters are recorded or calculated by transient analyzer. Recorded electric parameters are the arc current, arc voltage and arc power. An example of measured time functions of a test (part of a test protocol) is shown in **Fig. 2.**

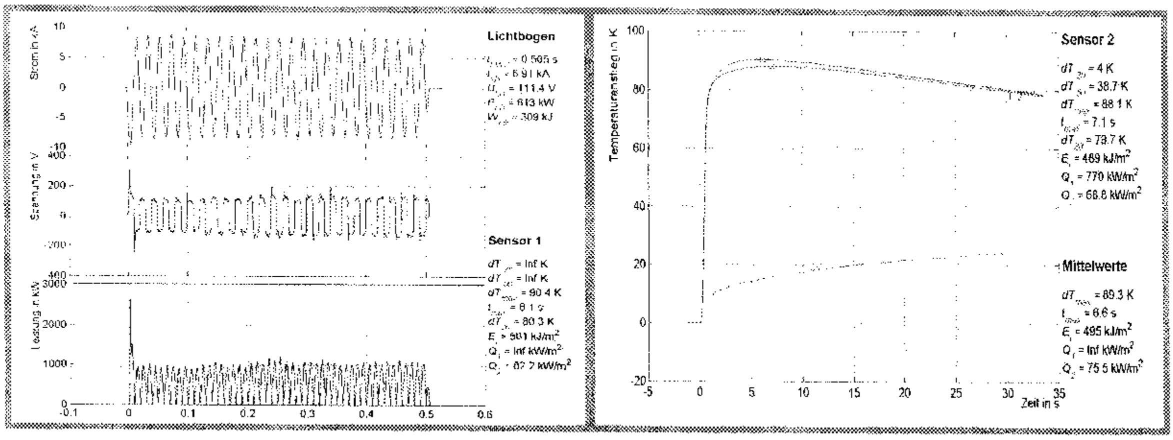

Fig. 2. Data recorded for a test: electrical parameters current, arc voltage and arc instantaneous power (left) and calorimeter temperature rises (right)

The calorimetric parameters primarily analyzed are the time curves of calorimeters temperature rises dT(t) as well as the maximum values dT_{max} (delta peak temperatures) and the related time points t_{max} (time to delta peak temperature).

The incident energy E_i transmitting the area A is proportional to the maximum temperature rise dT_{max}

$$E_i = \frac{m \cdot C_P}{A} \, dT_{max}$$

Using the actual mass m and specific heat values c_p of a copper calorimeter plate it is

Within one test, four arc shots are made under unchanged conditions. For passing a test it has to be

$$E_i = 5{,}54 \cdot \frac{dT_{max}}{°C} \cdot \frac{kJ}{m^2} = 0{,}132 \, \frac{dT_{max}}{°C} \cdot \frac{cal}{cm^2}$$

proved that there is no ignition/burning or afterflame of material (longer than 5 s), no melting-through and holes formation (larger than 5 mm), no breakopen, shrinkage, dripping,. charring, embrittlement as well as no loss of function of accessories in case of clothing.

In addition to these observation results the calorimetric quantities are assessed by the so-called Stoll criterion. The Stoll curve [4] is the criterion of the onset of second degree burning of human skin (see **Fig. 3**).

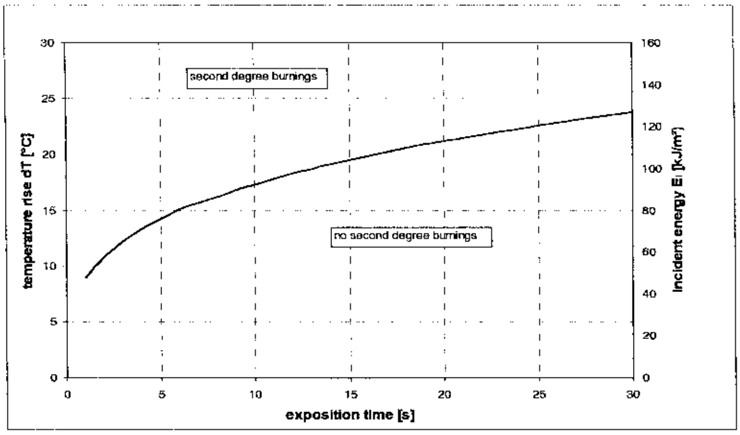

Fig. 3. Temperature and incident energy limits according to Stoll (delta peak temperature versus time to delta peak temperature)

The arc indices and thermal parameters presented in **Tab. 2** result from basic calorimetric measurements at the arc testing equipment described before.

Derived statistical mean values are shown for the case of direct arc exposure (without any reducing effect of textiles) under standard test conditions. Generally these values and particularly those of incident energy E_{i0} are statistically distributed within considerable scattering ranges because of the stochastic burning behaviour and transmission conditions of electric arcs.

These reference values allowing to assess the textile effects by comparing, are also important for quality management and assurance of the tests since a test may be checked referring to the deviations of actual exposure conditions to the standard ones (reproducibility of test conditions required). Naturally, the direct exposure values significantly exceed the limits of the Stoll curve to be kept for avoiding second degree skin burning.

Table 2. Arc indices and thermal test parameters

parameter	unit	class 1	class 2
test current I_P	kA	4	7
arc current I_{arc}	kA	3.4	5.8
arc voltage U_{arc}	V	110	125
arc active power P_{arc}	kW	342	640
arc energy W_{arc}	kWs	168	318
incident energy E_{i0}	kWs/m^2	135	423

4. Experiences from testing

Essential factors influencing testing are the ambient test conditions (indoor/outdoor, temperature, humidity, wind etc.), the initial test conditions and the box conditions. Frequent calibration checks of the test arrangements and parameters are necessary.

4.1. Test conditions and initial temperature

Tests should be carried out as an indoor test without ventilation during the test procedure at a ambient temperature T_a between 15 °C and 35 °C and a relative humidity of 25 % to 75 %.

When outdoor testing appropriate means are required to prevent effects of wind, rain etc. Testing should start not later than 5 min after the item under test is taken from the pre-conditioning atmosphere.

The calorimeter sensors shall be at an initial temperature of 15°C to 35 °C. The ambient temperature T_a and initial temperature of the sensors T_o is to be measured. It has to be guaranteed that the initial temperature of the sensors (for the temperature difference measurement by means of the thermocouples) is in a tolerance of $T_o = T_a \pm 2$ °C for test series. If necessary the sensors should be cooled by a jet of air or contact with a cold surface.

Decomposition products at the calorimeter sensor surface have to be removed. If condensed decomposition products become thicker than the paint layer the sensor should be cleaned by acetone or petroleum solvent. Frequently the active calorimeter surface shall be reconditioned by repainting of black colour. The same colour should be used for all sensors.

4.2. Preparing and conditioning of the box

The box shall be prepared and conditioned before testing. The box can be made of plaster. For this, plaster material should be used which gives a smooth and solid surface, e.g. moulding compound from ceramic powder or alabaster plaster.

The box must be in a dry and "conditioned" state. For preparing and conditioning the following instructions should be observed before testing:

- The box shall be dried in an oven with a temperature of about 60 °C for a period of 12 h. It shall be proved that the weight and the surface electrical resistance do not change more than 5 % at the end of the preparing process.
- Then a first arc shot shall be made before the use of the box for regular calibration and testing.

The box shall be cleaned after a test series of maximum 10 arc shots by removing metal particles and other sediments from the box surface. The box should be replaced after maximum 50 single arc shots.

4.3. Guaranteeing quality and reproducibility of testing

The test apparatus setting has to be checked for each test. Values recorded should be the arc current, arc duration, arc energy, and arc voltage. A graph of the arc current should be plotted to ensure proper waveform. In addition, the ambient temperature and relative humidity shall be recorded. Influence of wind or air convection flow during testing shall be prevented.

Calorimeter calibration

Calorimeters must be checked to verify proper operation. The temperature rise of each calorimeter and system response shall be measured. At 30 s no one calorimeter response may not vary more than 5% from the long term average of both calorimeters. Any calorimeter not meeting this requirement shall be replaced.

One acceptable method is to expose each calorimeter to a fixed radiant energy source for 10 s. For example the front surface of a 500 W spot light should be placed in a distance of about 10 mm to the calorimeter. The spot should be centred on at perpendicular to the calorimeter. At minimum calibration should be performed each testing day.

Before first placing of calorimeters within the plate the stationary temperature response is to be measured. Three stationary temperatures, e.g. T= 20 °C, T = 50 °C and T = 100 °C should be adjusted and measured for this.

Calibration of the electric test circuit and testing

Calibration oscillograms of the prospective test current adjusted and the test voltage proving the test conditions shall be recorded at least for each test series with unchanged test parameters, minimum once per week.

Before testing and after a test series, reference tests without material shall be carried out with measuring the direct exposure incident energy E_{io}.

It should be proved that this energy E_{io} of each sensor lies within a range of the double standard deviation ± 2 *s of the mean values according to Table 3. In the direct exposure shot before the test series, the direct exposure incident energy should additionally be greater than the long term mean value (Table 2 and 3).

Table 3. Statistically confirmed mean values of the direct exposure incident energy

Test current	Mean value E_{io}, kJ/m² (cal/cm²)	Double standard deviation ± 2*s, kJ/m² (cal/cm²)
Class 1: 4 kA	135 (3,2)	± 56 (1,3)
Class 2: 7 kA	423 (10,1)	± 78 (1,9)

For each of the tests the arc energy values shall be determined. A test is only valid if the arc energy W_{arc} ranges between the double standard deviation ± 2*s of the mean values according to Table 4. Otherwise the test shall be repeated.

Table 4. Ranges of the permissible arc energy

Test current	Mean value W_{arc} kJ	Double standard deviation ± 2*s, kJ
Class 1 : 4 kA	158	± 34
Class 2 : 7 kA	318	± 44

5. Selected textile test results

Fig. 4 gives an overview on typical test results which are found in testing selected flame resistant fabrics. All tested materials meet the requirements of a limited flame spread according to EN 533 respectively EN 531, Code A. The incident energy E_i is shown in dependence of the weight of the fabrics or fabric assemblies for testing conditions of the class 2 (7 kA). Each point is the average value for one material, classified by the kind of fibre material (flame retardant cotton; permanent heat resistant fibres). In general a exponential correlation is found. The protection will be improved with rising weight. Values are needed in the range of 550 ... 650 g/m² at least, to guarantee a transmitting heat flux below STOLL curve of 2nd degree burning.

There is a considerable deviation to the average curve in the certain test cases, actual tests shall be carried out in each case.

In addition to the weight, other textile parameters play also an important role, as fabric construction (weave texture, density), surface structure, surface finishing, heat shrinkage, air gaps/numbers of layers, behaviour against hot metal splashes and others.

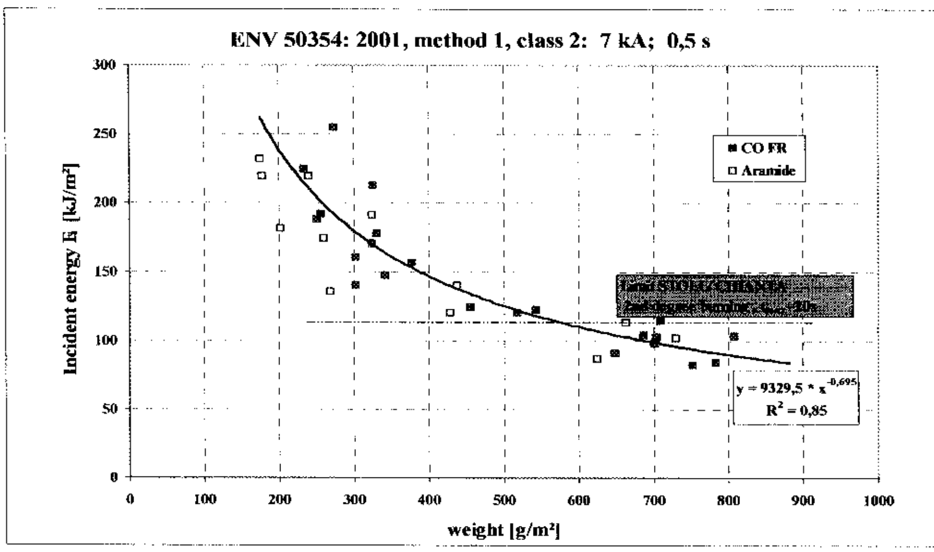

Fig. 4. Incident energy of heat resistant fabrics in dependency on the textile area weight for class 2 (7 kA)

6. Safety relevant aspects for testing and certification

With respect to an EC type examination the arc protection garment must satisfy basic safety requirements of the Directive 89/686/EEC in order to ensure the health protection and safety of users. There is the absolute need to test the arc resistance of the textile materials in each case. Therefore the evaluation of the fabric according to Method 1 of ENV 50354 extended with additional calorimetric heat flux measurement has to be always the first step.

General requirements like an afterflame time less than 5 sec, no melting through to the inside, no flaming debris and no hole formation > 5 mm in any direction as well as a maximum temperature rise T_{max} below the STOLL-curve at the backside of the specimen have to be fulfilled.

Additional factors are to be considered when garments are tested, such as accessories, seams, zips and closures, pockets, reflective stripes etc. The garment shall be designed in a way that no break-open occurs after being exposed to an accidental arc. Also the function of fasteners shall be still present. Design requirements, for example covered pockets and no exposed external metal parts, are quite comparable to the standard EN 470-1.
Due to these complex safety relevant aspects the STFI e.V. requires both the evaluation of the fabric (Method 1) and the test of the garment (Method 2) for a certification. In the near future the new IEC 61482-2 which is presently under consideration will specify all relevant requirements.

7. Summary

A test method for analyzing arc resistance and protecting effect of textile materials, fabrics and garments has been developed. The test procedure includes measuring of the heat flux. This box method is very well reproducible, near to practice and relatively favourable in price. It has being used for certifications.

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Authors: PD Dr.-Ing. habil. Holger Schau
Private Professor
Technische Universität Ilmenau
Faculty of Electrical Engineering and Informatics
Department of Electric Power Supply
P.O.B. 10 05 65
D – 98684 Ilmenau
Germany
Phone: ++49 3677 69 1489
Fax: ++49 3677 69 1496
e-mail: holger.schau@tu-ilmenau.de

Dipl.-Inf. Hendrik Beier
Sächsisches Textilforschungsinstitut e.V. (Saxon Textile Research Institute)
Head of Materials Research Department
Head of Certification Department
Annaberger Strasse 240
09125 Chemnitz
GERMANY
Phone: ++49 3 71 52 74-1 84
Fax: ++49 3 71 52 74-1 95
e-mail: hendrik.beier@stfi.de